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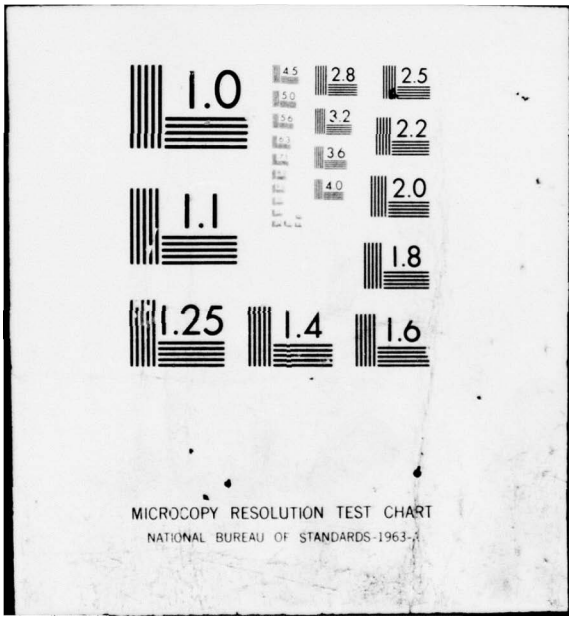
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This is the Final Report for a research grant whose objective was the development of efficient computer techniques for the processing of line-drawing images. A variety of specific problems were investigated. These included improved coding techniques for cartographic data, the reconstruction of solid-object descriptions from multiple-image projections of the objects, the removal of hidden lines from projections of both planar-faced and curved-surface objects, the design of a line-drawing analysis language called (over)

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20. Abstract continued.

CHAP and the development of a scheme for line-pattern classification.

TABLE OF CONTENTS

ABSTRACT

This is the Final Report for a research grant whose objective was the development of efficient computer techniques for the processing of line-drawing images. A variety of specific problems were investigated. These included improved coding techniques for cartographic data, the reconstruction of solid-object descriptions from multiple-image projections of the objects, the removal of hidden lines from projections of both planar-faced and curved-surface objects, the design of a line-drawing analysis language called CHAP and the development of a scheme for line-pattern classification.

1. SUMMARY OF RESEARCH

1.1 General

This is the Final Report for Grant AFOSR 76-2937 and spans the period 1 September 1975 through 31 August 1978. Two Interim Technical Reports* were issued during the grant period, one in October 1976 and the other in October 1977. In addition a total of 13 regular technical reports were issued and 19 articles were published in the technical literature. A complete listing of these items is given in Section 4 of this report. Some of the items have not yet appeared in print but have been accepted for publication.

Since the two Interim Technical Reports contained fairly comprehensive summaries of the respective preceding years, this report will summarize primarily only the research carried out during the last year of the grant, i.e., the period 1 September 1977 - 31 August 1978. During this period, the emphasis of the research was on the study of the characteristics of the so-called generalized chain codes, a new family of codes for representing cartographic and similar line-drawing type data. Work continued also on the debugging and refinement of CHAP, a computer language for line-drawing analysis. Other work was concerned with the representation and classification of shape, and with the description of three-dimensional scenes using data extracted from multiple images of the scene.

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*"Automatic Data Processing Techniques for Graphic-Data Display, Generation and Analysis", Interim Technical Report for Grant AFOSR 76-2937, CRL-50, 1 September 1975 - 31 August 1976, (AD-A033 315).

"Automatic Data Processing Techniques for Graphic-Data Display, Generation and Analysis", Interim Technical Report for Grant AFOSR 76-2937, 1 September 1976 - 31 August 1977, (AD-A049 317).

1.2 The Generalized Chain Coding Scheme

As a result of earlier research under this grant, it was discovered that the familiar basic 8-direction chain code could be effectively extended to a family of general chain codes, having attractive properties relative to compactness, precision, and smoothness. The characteristics of the new codes was examined and their relative advantages were described. It was discovered that for certain applications, some of the high-order chain codes (involving many more than the 8 directions of the basic code) were extremely advantageous via yielding reduced storage requirements, higher precision, shorter processing times, and greater smoothness of presentation. The results have been published in a number of articles [26-29].

1.3 The CHAP Line-Drawing Processing Language

For a number of years, algorithms for line-drawing processing had been developed and programmed by the principal investigator and his associates. These were collected into a single programming package called CHAP to facilitate their use in the project as well as for making them available to other researchers. The first version of CHAP was completed over a year ago. During the past year, the language was subjected to extensive testing and refinement, some additional subroutines were added, and a number of "bugs" were removed. Also a new set of user's and documentation manuals were prepared and distributed [24-25].

1.4 Representation and Classification of Shape

An investigation started during the previous year to develop an improved shape representation and classification scheme was continued. Emphasis was placed on the extraction of a variety of critical points, that is, points in a shape (such as corners, inflection points, curvature maxima, etc.) that could be uniquely identified and at which a shape could be unambiguously segmented. The technique developed proved to give good

results with a large variety of shaped and to be relatively modest in its demands on computer processing time. Shape classification is important for any kind of matching or fitting problem as well as, of course, for storing and retrieving line-drawing data according to shape (e.g. fingerprints, cartographic features) [30].

1.5 Modelling Scenes Using Data from Multiple Images

Work also was continued during the past year on a research study to develop effective techniques for constructing computer models of three-dimensional objects from data extracted from multiple images of the object. Few if any limitations were put on the geometry of the objects considered - they could be planar-faced, quadric-curved, or free-form curved. Efforts were concentrated on methods for creating such computer models in spite of serious imperfections in the source data. The source images could be low resolution and contain distortion, glare, haze and shadows. Papers describing the work were published during the past year [22, 31], or are to appear shortly [34].

2. ABSTRACTS OF RECENT PUBLICATIONS

2.1 H. Freeman, "Analysis of Line Drawings", in Digital Processing and Analysis, ed. by J. C. Simon and A. Rosenfeld, Noordhoff, Leyden, 1977.

Abstract: This paper is concerned with the computer analysis of line drawings. Line drawings serve as a medium for communication in a large variety of fields, and the processing to which they may be subjected is very much dependent on the application of interest. The paper discusses different types and features of line drawing, and reviews the more important schemes for quantizing and encoding them. Algorithms for analyzing line drawings are described, with particular emphasis on extracting geometric and shape-related features.

2.2 Keith P. Loepere, "CHAP User's Manual", Technical Report CRL-56, Rensselaer Polytechnic Institute, Troy, New York 12181, May 1978, 56 p.

Abstract: A computer representation for line drawings that has been found particularly convenient and has become widely accepted is the chain code. This representation is compact and allows most common processing functions to be performed efficiently.

CHAP is a collection of FORTRAN routines designed to process chain-encoded line drawings. Routines exist in CHAP to manipulate, synthesize, analyze, and do input and output upon chains. This report is intended to serve as a user's manual for CHAP. It describes the use of the CHAP routines along with other information needed to write a program utilizing the routines. A programming example is included.

2.3 Keith Loepere, "Documentation Manual for CHAP", Technical Report CRL-57, Rensselaer Polytechnic Institute, Troy, New York 12181, May 1978, 52 p.

Abstract: This is a documentation manual for the CHAP chain processing language. CHAP is a collection of routines developed for analyzing, synthesizing, and manipulating chain-encoded line drawings. This report describes the internal operation of the CHAP routines. It is a companion volume to the CHAP User's Manual.

2.4 Herbert Freeman, "The Generalized Chain Code for Map Data Encoding and Processing", Technical Report CRL-59, Rensselaer Polytechnic Institute, Troy, New York 12181, June 1978, 29 p.

Abstract: The concept of chain coding for map data based on the well-known 8-direction coding matrix is generalized to coding schemes involving 16, 24, 32, 48 and even more permissible directions for the line segment links in the chain representation. General methods for quantization and encoding are described. The different schemes are compared with respect to compactness, precision, smoothness, simplicity of encoding, and facility for processing. The resulting coding schemes appear to have desirable characteristics for map data processing applications because of their improved storage efficiency, smoothness, and reduced processing time requirements.

2.5 Herbert Freeman, "Application of the Generalized Chain Coding Scheme to Map Data Processing", Proc. 1978 Conference on Pattern Recognition and Image Processing, publ. 78CH1318-5C, IEEE Computer Society, 5855 Naples Plaza, Suite 301, Long Beach, CA. 90803, June 1978, pp. 220-226.

Abstract: The concept of chain coding based on the well known 8-direction coding matrix is generalized to coding schemes involving 16, 24, 32, 48 and even more permissible directions for the line segment links in the chain representation. General methods for quantization and encoding are described. The different schemes are compared with respect to compactness, precision, smoothness, simplicity of encoding, and facility for processing. The resulting coding schemes appear to have desirable characteristics for map data processing applications because of improved storage efficiency, smoothness, and reduced processing time requirements.

2.6 Herbert Freeman, "Some New Map Data Encoding Schemes", Proc. 3rd Jerusalem Conference on Information Technology, North-Holland Publ., Amsterdam, August 1978.

Abstract: Some new schemes for encoding map data are introduced. The schemes can be regarded as generalizations of the well known 8-direction chain coding scheme. Instead of being limited to 8 types of links for approximating a curve, the new schemes possess 16, 24, 32, 48, or even more link types. The new schemes permit increased smoothness of representation, exhibit greater precision, and require less processing time for comparable resolution than present methods.

2.7 H. Freeman and A. Saghri, "Generalized Chain Codes for Planar Curves", to be presented at the 4th International Joint Conference on Pattern Recognition, Kyoto, Japan, November 7-10, 1978.

Abstract: This paper describes a set of line-segment-approximation codes for the representation of planar curves. The codes, which represent generalizations of the common 8-direction chain code to 16, 24, 32, 48 and even more valid directions, have improved characteristics in terms of compactness, precision, smoothness and processing efficiency. The paper describes the quantization procedures for these generalized chain codes, relates their efficacy to the radii-of-curvature spectra of the curves to be represented, and develops criteria for the selection of the appropriate code and grid spacing.

2.8 Herbert Freeman, "Shape Descriptions via the Use of Critical Points", Pattern Recognition, Vol. 10, 1978, pp. 159-166.

Abstract: A key element in pattern recognition is the description of shape. For two-dimensional objects (blobs), shape is conveyed by the curving of the boundary line and is normally considered independent of scale and orientation. The curving may be regarded as concatenation of arcs of varying instantaneous radii of curvature, possibly interspersed occasionally by discontinuities. The description of shape is facilitated by segmenting the boundary line at so-called critical points - corners (discontinuities in curvature), points of inflection, and curvature maxima. Additional critical points are intersections and points of tangency. Algorithms are described for extracting such critical points in the presence of noise. An illustration is given showing how the critical points may be used in the development of a shape description system.

2.9 R. Shapira and H. Freeman, "Computer Description of Bodies Bounded by Quadric Surfaces from a Set of Imperfect Projections", IEEE Trans. on Computers, Vol. C-27, (9), September 1978, pp. 841-853.

Abstract: This paper describes a computer program for constructing a description of solid bodies from a set of pictures taken from different vantage points. The bodies are assumed to be bounded by faces which are planar or quadric, and to have vertices formed by exactly three faces. It is assumed that a preprocessor provides the program with line and junction information which it has extracted from the pictures. The preprocessor is expected to make mistakes, such as losing features or providing misinformation about their nature. A technique is presented for validating doubtful features as well as for matching corresponding features extracted from the different pictures. New grammar rules are developed for line-drawing projections of curved and planar bodies and are used as a tool in the scene analysis process. Each picture's data analysis is supported dynamically by the results obtained thus far in the other pictures' analysis. The analyzed data from all pictures are grouped into sets, each corresponding to a single face (flat or curved), whose nature is also determined. The sets are grouped again to correspond to the different bodies in the scene. The program written in PL/I has been tested successfully on several scenes.

2.10 Herbert Freeman, "Algorithm for Generating a Digital Straight Line on a Triangular Grid", accepted for publication in IEEE Trans. Computers.

Abstract: An algorithm is presented for generating the optimum straight-line approximation for a plotter constrained to move a unit distance at a time in one of six equi-spaced directions. The algorithm facilitates the drawing of digital straight lines on a triangular grid.

2.11 J. Feder, "Plex Languages", Information Sciences, (3), 1971, pp. 225-241, (AD-A049 400).

Abstract: The phase-structure grammar scheme used for specifying string languages is extended to structures called plexes composed of symbols with an arbitrary number of "attaching points". Classes of plex languages that parallel existing classes of string languages are defined, and these classes are shown to be distinct. Context-free grammars for languages of chemical structures, logic diagrams, electrical circuits, and flowcharts are given. Plex languages are used to specify the interconnection of encoded geometric curves to form mesh-like line patterns, and methods are given by which languages of such line patterns can be classified.

3. PRESENTATIONS
1 September 1977-31 August 1978

3.1 Herbert Freeman, "On the Template Layout Problem", Department of Computer Science Colloquium, University of North Carolina, Chapel Hill, N. C., 31 October 1977.

3.2 _____, "Computer Scene Analysis", Department of Electrical Engineering Colloquium, McGill University, Montreal, Canada, 20 December 1977.

3.3 _____, "Efficient Line Drawing Representation through the Use of Generalized Chain Code", Engineering Foundation Conference on Algorithms for Image and Scene Analysis, Asilomar, California, 19-24 February 1978.

3.4 _____, "Research in Computer Graphics and Scene Analysis", Computer Center Seminar, University of Calabria, Italy, 22 March 1978.

3.5 _____, "Shape Characterization by the Method of Roving Line-Segment Scanning", IEEE Computer Workshop on Pattern Recognition and Artificial Intelligence, Princeton, N. J., 12-14 April 1978.

3.6 _____, "Lines, Curves, and the Representation of Shape, Computer Science Summer Institute, Lecce, Italy, 14-15 July 1978.

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The following is a complete list of publications resulting from the research grant during the period 1 September 1975 through 31 August 1978.

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2. M. Adamowicz and A. Albano, "A Solution to the Rectangular Cutting-Stock Problem", IEEE Trans. on Systems, Man and Cybernetics, Vol. SMC-6, (4) April 1967.

3. J. Z. Levin, "A Parametric Algorithm for Drawing Pictures of Solid Objects Bounded by Quadric Surfaces", Tech. Rept. CRL-46, Computer Research Laboratory, Electrical and Systems Engineering Dept., Rensselaer Polytechnic Institute, Troy, New York 12181, March 1976.

4. H. Freeman, "Analysis of Line Drawings", Proc. NATO Advanced Study Institute on Digital Image Processing, 14-25 June 1976, Bonas, France (to be published in book form, preprints available). (Proceedings available through IRIA, Rocquencourt, France.)

5. R. Shapira and H. Freeman, "A Cyclic-Order Property of Bodies with Three-Face Vertices", Tech. Rept. CRL-42, Div. Appl. Sci., New York University, August 1975.

6. J. Z. Levin, "A Parametric Algorithm for Drawing Pictures of Solid Objects Bounded by Quadric Surfaces", presented at Third Annual Conference on Computer Graphics, Interactive Techniques, and Image Processing, Philadelphia, 14-16 July 1976. Appeared also in special issue on computer graphics, Communications of the ACM, Vol. 19, (10), October 1976.

7. R. Shapira, "Computer Reconstruction of Bodies Bounded by Quadric Surfaces from a Set of Imperfect Projections", Tech. Rept. CRL-48, Rensselaer Polytechnic Institute, September 1976.

8. R. Shapira, "A Technique for the Reconstruction of a Straight-edge, Wire-frame Object from Two or More Central Projections", Comp. Graphics and Image Proc., 3, (4), Dec. 1974, 318-326, (AD 751 282).

9. A. Rabinowitz, "Reconstruction of Polyhedra from Sets of Their Perspective Projections", Tech. Report 403-20, Doctoral dissertation, Department of Electrical Engineering, New York University, Bronx, New York, April 1971, (AD 732 300).

10. R. Shapira, "Computer Reconstruction of Quadric-Surfaced Objects from Two or More Visible-Line Projections", Tech. Rept. CRL-44, Div. Appl. Sci., New York University, August 1975, (AD-A02 628).

11. A. Albano, "Representation of Digitized Contours in Terms of Conic Arcs and Straight-Line Segments", Comp. Graphics and Image Proc., 3, 1974, 318-326.

12. E. U. Ramer, "The Transformation of Photographic Images into Stroke Arrays", IEEE Transactions on Circuits and Systems, Vol. CAS-22, No. 4, April 1975, pp. 363-374.

13. E. U. Ramer, "Extraction of Line Structures from Photographs of Curved Objects", Comp. Graphics and Image Proc., 4, 1975, 81-103.

14. H. Freeman, "Computer Processing of Line-drawing Images", Computing Surveys, 6, (1), March 1974, 57-97, (AD 777 929).

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18. H. Freeman, "Shape Description via the Use of Critical Points", Proc. IEEE Conference on Pattern Recognition and Image Processing, IEEE Publ. 77CH1208-9C, June 6-8, 1977, pp. 168-174, (AD-A040 273).

19. M. Potmesil, "QUADRAW User Manual", Tech. Report CRL-53, Rensselaer Polytechnic Institute, Troy, New York, 75 p., June 1977.

20. H. Freeman, J. Paolicelli, and M. Potmesil, "Programmer's Manual for the CHAP Line-Drawing Processing Language", Tech. Report CRL-52A, Rensselaer Polytechnic Institute, Troy, New York, 82 p., Revised June 1977. Note: This is a revised and up-dated version of Tech. Report CRL-52.

21. R. Shapira and H. Freeman, "Reconstruction of Curved-Surface Bodies from a Set of Imperfect Projections", Proc. 5th Int'l. Joint Conf. Artificial Intelligence, publ. by Dept. of Computer Science, Carnegie Mellon Univ., Pittsburgh, Pa. 15213, August 1977, pp. 628-634.

22. R. Shapira and H. Freeman, "A Cyclic-Order Property of Bodies with Three-Face Vertices", IEEE Trans. Computers, C-26, (10), October 1977.

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33. J. Feder, "Plex Languages", Information Sciences, (3), 1971, pp. 225-241, (AD-A049 400).

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